PALE BLUE DOT II - SESSION 4 - TALKS TOON, KOSTIUK, SLANGER;

Chris Potter talk

In the Earth Sciences for several years now, we have been integrating local sources of gas emissions into regional and global atmospheric budgets. Within ecosystems, the role of functional groups is important. The atmosphere sees the effects of net ecosystem productivity and net gas exchange. Thus it is important to quantify the transitions from ecosystem processes to gas production to gas exchange with the atmosphere. One needs global datasets, namely a truly balanced sampling of all major sources, in order to reconstruct global budgets accurately, particularly back in geologic time. All of this is required to deconvolve the biological contributions from the geologic contributions. A quantitative model must be constructed with sufficient detail to account for sources and sinks at all scales. Then the model must be continually verified and/or revised, based upon observations of the atmosphere, its variability, geographic patterns, etc. For example, a new class of global models for vegetation is being developed to predict ecosystem changes into the future, based upon projections of land use and climate. Models have been developed specifically for the budgets of key gases such as CH_4, N_2O, and NO_2. For example, CH_4 emissions depend critically upon water budgets, and wetlands are very important. We can address the effect of seasonality upon the sources of CO_2 and CH_4. The northern and southern hemispheres behave differently, therefore a multipixel remotely-sensed image of the Earth might detect seasonal hemispheric differences due to the biosphere. We can construct global emission budgets for the major gases (carbon and sulfur compounds), that include components from the land, wetlands, and the regions of the oceans. CO_2 and CH_4 have big land-based components, for example. There are gaps in our current coverage of the global budgets for the key gases. We still don't have good budgets for the CH_4 sources in ecosystems at high latitudes and in the remote tropics. But we have good data from other regions. What about an earlier biosphere, one that was dominated by microbial mats? Unfortunately we do not have a very robust database. However, there have been some studies of microbial mat processes as a function of salinity, temperature, water and nutrient requirements, etc. We are beginning to refine such models to give quantitative estimates of rates of processes, with possible extensions to gas emissions. Major controls include the incoming radiation as well as various substrates. The effects of the daily (24 hour) cycle are also being incorporated, and we are beginning to see reasonable agreement with field measurements, at least for O_2 fluxes. The next step would be to map out the paleogeography of the Earth to understand the distribution of key environments such as the shallow seas. Undoubtedly we will need data for available radiation and nutrients, for other environments, for example, to complete this treatment. Applying these models at various times in Earth history could then give us the beginnings of a historical model for the evolution of atmospheric composition. This is a very ambitious enterprise, but this presentation at least has identified the key elements that must be included in any effort to reconstruct paleoatmospheric budgets. As our models of the present atmosphere become more mechanistic and include a more comprehensive treatment of feedback effects, these models of the present-day Earth will guide our efforts to develop models both for the geologic past and for the future.

Christie Boering talk

This talk will address what will happen as these biogenic gases enter the atmosphere and are transformed there, at least for the Earth's modern atmosphere. The fate of these gases depends upon the mechanisms for their destruction, namely direct photolysis or secondary chemical reactions. In the early anoxic Earth, the lifetime (half-life) of atmospheric CH_4 was about 10,000 years, compared to about 10 years in the present oxic atmosphere. Thus, a present-day biogenic CH_4 flux might support a CH_4 concentration of as much as one percent, in an anoxic atmosphere that also had some H_2 available to destroy OH radicals that are produced from water vapor photodissociation. Thus a consideration of destruction processes is very important, especially as we try to extrapolate our estimates to include other planets.

A consideration of atmospheric chemistry is best subdivided into studies of tropospheric and stratospheric processes. The atmospheric temperature profile gives an important perspective, as does the vertical transport. The ozone budget is illustrative. The UV flux can photodissociate O_2 in the stratosphere, and the O atoms recombine with O_2 to form O_3, releasing energy that is carried away by other species. This sustains the heating of the stratosphere. Both UV-C photodissociation and reaction with O destroy O_3 (Chapman reactions), and explain the spectral nature of the UV shield, the vertical stratospheric temperature structure, and the vertical distribution of O_3. The temperature structure sustains the stratification of the stratosphere and thus the rate of vertical transport of gases there. The peak in concentration of O_3 at a discrete altitude in the stratosphere reflects the optimal combination of O_2 concentration and UV photons. In the 1960's, it was discovered that the rate of production of O_3 was five times the rate of loss via the Chapman reactions, yet the O_3 concentration was roughly at steady state. This led to the search for other loss mechanisms. Paul Crutzen and others showed that O_3 could also suffer catalytic destruction due to certain free radical species, even at very low concentrations. Nitrogen oxide species are important agents of destruction and are produced by microbial soil activity. N_2O is destroyed principally in the stratosphere. Another key species is the OH radical, which can be produced by dissociation of water vapor created in the stratosphere by the photodissociation of CH_4. Chlorine species are important, and they have both natural and anthropogenic (e.g., CFCs) sources. The variation in the rates of the various reactions that determine the O_3 budget creates a feedback effect that stabilizes temperature. Other greenhouse gases also have feedback mechanisms that add stability to climate.

In the troposphere, electronically excited O atoms are sustained by O_3 decomposition. The abundant water vapor sustains a robust population of OH radicals. OH is the primary "detergent" that keeps the inventories of H-containing reduced gases at very low levels. Thus CH_4 is destroyed by OH, which explains its short lifetime today, Destruction of CH_4 also produces CO. Could other biogenic marker gases (hydrocarbons, methylated species, sulfur species) be detectible remotely? In the current atmosphere, the OH radical keeps these at the ppb or ppt levels, so they are probably not detectible. Other oxidants such as chlorine species can also be important agents of destruction.

How might other planets differ from Earth? Halogens might be the dominant oxidants, for example. If O_3 were not as prominent, the O_3-sustained UV filter would be weaker, and thus the UV would penetrate the troposphere and influence its chemistry. Vertical transport rates would differ because vertical thermal stratification due to O_3 would be less important. Seasonal variations would probably be hard to detect remotely; even CO_2 variations are hard to detect from Earth orbit. Therefore, one should be very cautious about trading off spectral resolution to obtain spatial resolution.

TOON:

Tutorial on clouds: how they work and what kinds of clouds we might find on other planets. Why care? (1) They get in the way—and might not even be detectable, especially if cloud cover is complete, because they are often spectrally neutral. (2) Clouds can tell us a lot about the physics and chemistry of the atmosphere. (3) They certainly can have a major effect on the climate system.

What is the cloud cover? Note that a plot of cloud cover versus atmospheric mass shows that there is a transition around the mass of the Earth's atmosphere between very little cover and essentially 100%--the more atmosphere a planet has retained, the more cloud cover there is likely to be.

What do we mean by a cloud? To get at this, consider how clouds are produced: condensation/evaporation of high vapor pressure material, produced by temperature fluctuations due to dynamics of atmosphere, and lots of different chemical compositions are possible; mechanically generated—made by crushing or breaking something and blowing it into the air; and photochemical generation of a low vapor pressure compound, which stays around for a long time because it doesn't evaporate easily.

Mars has a small percentage of cloud cover—not enough water to resupply clouds. Earth has about 60% cloud cover, and this number is driven by the atmospheric dynamics. Titan has 100% cloud cover—a photochemical cloud, organic compounds, with the top of the deck about 200 km above the surface. Only long wavelengths can penetrate through these clouds to the surface. Venus is totally covered, of course—and it's yellow, but no one knows why. The cloud top is at about 70 km, so again it is tough to see below this level except at long wavelengths. (In the near IR there are windows through the cloud decks of Venus and Titan that allow penetration much deeper.) Jupiter has many layers of condensational clouds to give total cloud cover. The colors of Jupiter's clouds are again a mystery.

The sizes of the particles making up clouds vary over a tremendous range, and therefore the lifetimes in the atmosphere vary also over large ranges. Even a single system of aerosols or clouds covers a wide range, maybe 3 orders of magnitude, in size. So that complicates the system and the physics that describes it. To study cloud mass, need to look at the larger particles, but to look at number of particles, need to observe at correspondingly shorter wavelengths. Alternatively, information about the sizes of particles in clouds tells about the origin of the particles and therefore the clouds.

Whether or not it rains and whether or not clouds are necessary to that process, depend on the particular physics of the atmosphere and particles in it. On the Earth, of course, it is generally true that clouds are required for rain, whereas on other planets that may well not be the case.

Lifetimes of soluble gases in the atmosphere have their lifetimes controlled by rainfall, therefore clouds can play a big role in atmospheric chemistry. Lightning….see abstract.

Spectroscopy of clouds. Nice simple atmosphere like Mars, not much there, can get a good spectrum. But that's not typical. Looking at Earth clouds, we see that the spectrum depends strongly on the particle size. In planetary atmospheres where cloud cover is high, much thought has to go into the wavelengths of observation, because penetration of the clouds is a big issue.

KOSTIUK…..

Purpose of this talk is to discuss spectral signatures of Earth and other planets in the solar system, and to discuss what information can be gleaned from the spectra. Advantages of the thermal infrared include the enhanced contrast ratio, as well as the presence of strong emission lines of important atmospheric molecules in this region. And these are well-studied molecular spectra, so we can hope to use them to study the planet's atmosphere.

We have a lot of information on our own solar system, gathered over the years using a number of instruments on spacecraft. Types of planets can be classified from their strong spectral features. Terrestrial planets show prominent bands of CO2, ozone, and, in the case of the Earth, water. The outer planets are dominated by hydrocarbon emissions from acetylene, methane, ethane, and, in the case of Jupiter, substantial amounts of ammonia. Using these dominant spectral features, one can clearly separate oxidizing from reducing atmospheres.

Now, if we can make spectral measurements at the required resolution and S/N, a lot of information about the composition and physics of the atmosphere can be retrieved. At high resolution, it is possible to measure dynamics in the atmosphere, as well as orbital motions.

The radiative transfer equation, which defines what an observer will see, can be written down. Applying this equation can provide a lot of information about the atmosphere. For example, the atmospheric profile of T vs. P can be determined with the proper spectral information. As the spectral resolution is increased (by orders of magnitude) the amount of information in the spectra and the kinds of things we can learn, grow strongly. Of course this is very high resolution and requires a strong signal, or at least good S/N.

In looking at extra-solar systems, the planet will not be resolved in the beam of the telescope. It is important to note that when the planet is smaller than the beam size, many effects are integrated to get the eventual output signal, including the dynamics, radiative transfer (limb brightening), and temperature variations across the disk. An analytic method has been developed to allow for modelling of this effect, and has been written so as to include the case where more than one planet may be in the beam of the telescope. Note that having multiple planets in the field of view can lead to some confusion. The goal should be to avoid this case, but when it can't be avoided, it's useful to have such an analysis to apply.

There is a unique phenomenon, characteristic of CO2 atmospheres: non-thermal emission from the upper atmosphere. In the case of Venus, at very high resolution this emission has been detected, and has been identified as due to molecular laser emission. For Venus this emission would be very difficult to detect at extra-solar distances. But one could imagine a case where the effect was stronger and potentially useful as a probe for the planetary system.

In observing planets at high spectral resolution, the big problem is distance and the only solution is larger telescope apertures. This is a long term goal, but it will allow us eventually to get better information on temperature, pressure, and abundances, which is critical to interpret the atmospheric chemistry and biological potential.

TOM SLANGER…..

This talk focused on what can be done using the Echelle spectrometer on the Keck telescope. This instrument provides the best nightglow spectrua that have been seen to date. Now, nightglow spectroscopy will not be relevant to the early observations of extra-solar planets because of the sensitivity and spatial resolution that are required to detect it and separate it from the dayglow, but nightglow could be of interest down the road.

Presently, of course, the nightglow spectra are background for ground-based astronomical observations, so they are cataloged only for calibration of the astronomical observations. These spectra are provided to aeronomers for study of the upper atmosphere. Of particular recent interest to us has been the 0-1 band in O2. This is the only O2 nightglow band to be seen from the ground with reasonable resolution. In attempts to see the 0-0 band from the ground, we see combined absorption and emission (when using a resolution of 0.2 Angstroms), where the emission which is seen comes from the isotopic bands of O2. The question arises: what produces the light which is absorbed, since these are nightime observations? There are various sources, including the nightglow emission itself.

Many features can be identified in the nightglow spectra, including Na, which comes from chemistry with O3. If detected, this could provide some (indirect) information about O3 in an atmosphere. Potassium has been detected, with the high resolution and sensitivity that Keck provides. OH is seen throughout a broad wavelength range. In the terrestrial atmosphere, the main source of OH is through dissociation of water and O2, and that can again give indirect evidence of water and oxygen in a planetary atmosphere. Although the Earth is bright to Keck, OH emission from an extra-solar planet would still be much to faint to detect. The green line of O2 can help to differentiate between an oxygen atmosphere and a CO2 atmosphere, such as is seen on Venus. However, one can get a false positive from the emission lines. For example, on Venus, dissociation of CO2 in the upper atmosphere can produce oxygen features that could be misinterpreted. Such an effect as measured in the 63 micron line of oxygen would also give a false positive. Absorption is the key to determining the total oxygen abundance.

So, if an when we get to the capability to measure such lines in extra-solar planetary atmospheres, there may be some important diagnostics, particularly OH for evidence of water in the atmosphere.